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(54) Title of the invention: Exposure Method and Exposure Apparatus

(57) Abstract

Purpose: To provide a light-exposure method capable of enhancing the throughput and deciding the size of a substrate stage irrespective of a base line amount.

Configuration: For example, while a pattern image of a mask R is exposed to light via an optical projection system PL on a substrate W held on a stage WS2, (1) a location relationship between a positioning mark on the substrate W held on a stage WS1 and a reference point on the stage WS1 is measured. After the exposure of the substrate W held on the stage WS2 is completed, under a state in which a reference point on the stage WS1 is positioned in the projection region of the projection optical system PL, (2) location deviations of the reference point on the stage WS1 with respect to a predetermined reference point in the projection region and (3) a coordinate location of the stage WS1 at the time of detecting the location deviations are detected. Thereafter, movements of the stage WS1 are controlled based on the detection results of (1), (2) and (3), and the substrate W held on the stage WS1 is positioned to the pattern image of the mask R.

Scope of Patent Claims

Claim 1

An exposure method for exposing a pattern image formed on a mask via a projection optical system onto sensitive substrates, comprising the steps of:

preparing two substrate stages, each of which is movable independently in the same plane while holding a sensitive substrate;

exposing the pattern image of the mask on the sensitive substrate held on one of the two substrate stages via the projection optical system;

measuring the positional relationship between an alignment mark on the sensitive substrate held on the other of the two substrate stages and a reference point on the other stage during exposure of the sensitive substrate held on the one substrate stage;

detecting the positional deviation of the reference point on the other substrate stage from a predetermined reference point in a projection area of the projection optical system and the coordinate position of the other substrate stage, with the reference point on the other substrate stage being positioned in the projection area, after completion of exposure of the sensitive substrate held on the one substrate stage; and

controlling the movement of the other substrate stage on the basis of the detected positional relationship, the detected positional deviation and the detected coordinate position to perform positional alignment between the sensitive substrate held on the other stage and the pattern image of the mask.

Claim 2

An exposure apparatus for exposing a pattern onto sensitive substrates via a projection optical system, comprising:

a first substrate stage which is movable in a two-dimensional plane while holding a sensitive substrate;

a second substrate stage which is movable independently from the first substrate stage in the same plane as that of the first substrate stage while holding a sensitive substrate;

an alignment system, provided apart from the projection optical system, for detecting a mark on the substrate stage or a mark on the sensitive substrate held on the stage;

an interferometer system for measuring the two-dimensional positions of the first substrate stage and the second substrate stage;

a moving means for moving each of the two substrate stages between a predetermined first position in a stage movement range at the time of exposure during which the sensitive substrate held on the stage is exposed via the projection optical

system, and a predetermined second position in a stage movement range at the time of alignment during which the mark on the stage or the mark on the sensitive substrate held on the stage is detected by the alignment system; and

a controller for controlling the actions of the two stages while monitoring the measured values of the interferometer system so that during exposure of the sensitive substrate held on one of the first substrate stage and the second substrate stage, a mark detecting action by the alignment system is performed on the other of the first substrate stage and the second substrate stage, and then controlling the moving means to interchange the positions of the one substrate stage and the other substrate stage.

Claim 3

The exposure apparatus according to claim 1,

wherein the interferometer system has a first measuring axis and a second measuring axis that intersect each other perpendicularly at the center of projection of the projection optical system, and a third measuring axis and a fourth measuring axis that intersect each other perpendicularly at the center of detection of the alignment system, and

wherein the controller resets the measuring axes of the interferometer system when interchanging the positions of the one stage and the other stage.

Claim 4

An exposure apparatus for exposing a pattern onto sensitive substrates via a projection optical system, comprising:

a first substrate stage which is movable in a two-dimensional plane while holding a sensitive substrate;

a second substrate stage which is movable independently from the first substrate stage in the same plane as that of the first substrate stage while holding a sensitive substrate;

an alignment system, provided apart from the projection optical system, for detecting a mask on the substrate stage or a mark on the sensitive substrate held on the stage;

an interferometer system for measuring the two-dimensional positions of the first substrate stage and the second substrate stage;

moving means for moving each of the two substrate stages among three locations, i.e., a predetermined first position in a stage movement range at the time of exposure during which the sensitive substrate held on the stage is exposed via the projection optical system, a predetermined second position in a stage movement range at the time of alignment during which the mark on the stage or the mark on the sensitive substrate held on the stage is detected by the alignment system, and a third position at which the sensitive substrate is passed between the substrate stage and an external substrate carrier mechanism; and

a controller for controlling the two stages and the moving means so that while the position of one of the first and second substrate stages is managed by the interferometer system and the sensitive substrate held on the one stage is exposed with the pattern via the projection optical system, the replacement of the sensitive substrate, and an alignment action for measuring the positional relationship between the alignment mark on the sensitive substrate and a reference mask on the other stage based on the results of detection by the alignment system and the measured values by the interferometer system are sequentially performed on the other of the first and second substrate stages, and for controlling the two stages and the moving means so that after the actions on the two stages are both completed, the actions to be performed on the two stages are interchanged.

Claim 5

The exposure apparatus according to claim 4, further comprising:

a mask with the pattern formed thereon,

wherein a pattern image formed on the mask is projection-exposed via a projection optical system onto the sensitive substrates on the first substrate stage and the second substrate stage

Claim 6

The exposure apparatus according to claim 5,

wherein the interferometer system has a first measuring axis and a second measuring axis that intersect each other perpendicularly at the center of projection of the projection optical system, and a third measuring axis and a fourth measuring axis that intersect each other perpendicularly at the center of detection of the alignment system, and

wherein the controller resets the first and second measuring axes of the interferometer system in moving each of the two stages to the first position, and resets the third and fourth measuring axes of the interferometer system in moving each of the two stages to the second position.

Claim 7

The exposure apparatus according to claim 6, further comprising:

a mark position detector for detecting the relative positional relationship between the projection center of the pattern image of the mask and the reference point on the stage via the mask and the projection optical system.

Claim 8

The exposure apparatus according to any one of claims 2 to 7,

wherein each of the substrate stages has a stage body and a substrate holding member detachably mounted on the body for holding the substrate, a reflecting surface for the interferometer system is provided on the side surface of the substrate

holding member, and a reference mark as the reference point is formed on the upper surface of the substrate holding member, and

wherein the moving means moves the substrate holding member among the respective locations instead of the substrate stage.

Claim 9

The exposure apparatus according to any one of claims 2 to 8,

wherein the moving means includes a robot arm.

Claim 10

The exposure apparatus according to any one of claims 2 to 9,

wherein a fixed mirror serving as a reference for measurement by the interferometer system is attached to each of the projection optical system and the alignment system.

Claim 11

The exposure apparatus according to any one of claims 2 to 10, further comprising:

in addition to the first substrate stage and the second substrate stage, at least one other substrate stage movable independently of the two substrate stages in the same plane as that of the stages while holding a sensitive substrate.

Detailed Description of the Invention

[0001]

Industrial Field of Utilization

The present invention relates to an exposure method and an exposure apparatus. More specifically, the present invention relates to an exposure apparatus and an exposure method for exposing a mask pattern, which is used for producing semiconductor elements or liquid crystal display elements by means of a lithography process, onto sensitive substrates via a projection optical system, and relates to an exposure apparatus such as an image drawing apparatus that directly draws a pattern on the sensitive substrate by a charged particle beam or the like other than a laser light and an electron beam to manufacture a mask for manufacturing semiconductor elements. The present invention is characterized by having a plurality of substrate stages for holding the sensitive substrates.

[0002]

Prior Art

Various exposure apparatuses have been hitherto used, for example, when semiconductor elements or liquid crystal display elements or the like are produced by means of the photolithography process. At present, a projection exposure apparatus is generally used, in which an image of a pattern formed on a photomask or reticle (hereinafter referred to as "reticle") is transferred via a projection optical system onto a substrate (hereinafter referred to as "sensitive substrate" or “wafer”, if necessary)

such as a wafer or a glass blade applied with a photosensitive material such as photoresist on its surface. In recent years, a reduction projection exposure apparatus (so-called stepper) based on the so-called step-and-repeat system has been predominantly used as the projection exposure apparatus, in which a sensitive substrate is placed on a substrate stage which is movable two-dimensionally, and the sensitive substrate is moved in a stepwise manner (subjected to stepping) by using the substrate stage to repeat the operation for successively exposing the image of the pattern formed on the reticle to the respective shot areas on the sensitive substrate.

[0003]

Recently, a projection exposure apparatus based on the step-and-scan system (scanning type exposure apparatus as described, for example, in Japanese Unexamined Patent Application Publication No. 7-176468), which is obtained by applying modification to the stationary-type exposure apparatus such as the stepper, is also used frequently. The projection exposure apparatus based on the step-and-scan system has, for example, the following merits. That is, (1) the projection optical system is easily produced because a large field can be exposed by using a smaller optical system as compared with the stepper, and a high throughput can be expected owing to the decrease in number of shots because a large field is exposed. Further, (2) an averaging effect is obtained owing to relative scanning of the reticle and the wafer with respect to the projection optical system, and thereby it is possible to expect improvement in distortion and depth of focus.

[0004]

With this type of projection exposure apparatus, positioning (alignment) between the reticle and the wafer needs to be performed highly precisely prior to exposure. To carry out this alignment, the wafer is provided with a position detecting mark (alignment mark) formed (exposure transferred) by a previous photolithographic process. By detecting the position of this alignment mark, the exact position of the wafer (or a circuit pattern on the wafer) can be detected.

[0005]

Alignment microscopes for detecting the alignment mark are roughly classified into an on-axis type for detecting marks via a projection lens, and off-axis type for detecting marks without allowing the detecting light to pass via a projection lens. With regard to a projection exposure apparatus with an excimer laser light source, which would be predominant in this field, an alignment microscope of the off-axis type is optimal. This is because the projection lens has been corrected for chromatic aberration due to exposure light, so that the on-axis type cannot condense alignment light, or if it could, an error due to chromatic aberration would be marked. An alignment microscope of the off-axis type, on the other hand, is provided separately from the projection lens; therefore, free optical design is possible without

regard for such chromatic aberration, and various alignment systems can be used. For example, a phase contrast microscope or a differential interference microscope may also be used.

[0006]

The outline of the flow of the process in such a projection exposure apparatus is as follows.

[0007]

(1) At first, a wafer load step is performed, in which a wafer is loaded on a wafer table by using a wafer loader, and then a so-called search alignment is performed on the basis of the contour of the wafer or the like.

[0008]

(2) Next, a fine alignment step is performed, in which the positions of each of the shot areas on the wafer are accurately determined. In general, the EGA (enhanced global alignment) system is used for the fine alignment step. In this system, a plurality of sample shots included in the wafer are selected beforehand, and positions of alignment marks (wafer marks) affixed to the sample shots are successively measured. Statistical calculation based on, for example, the so-called least square method is performed on the basis of results of the measurement and designed values of the shot array to determine all shot array data on the wafer (see, for example, Japanese Unexamined Patent Application Publication No. 61-44429). In this system, it is possible to determine the coordinate positions of the respective shot areas with high accuracy at a high throughput.

[0009]

(3) Next, an exposure step is performed, in which the image of the pattern on the reticle is transferred onto the wafer via the projection optical system while successively positioning the respective shot areas on the wafer to be located at exposure positions on the basis of the coordinate positions of the respective shot areas having been determined in accordance with the EGA system or the like described above and the previously measured baseline amount.

[0010]

(4) Next, a wafer unload step is performed, in which the wafer on the wafer table having been subjected to the exposure process is unloaded by using a wafer unloader. The wafer unload step is performed simultaneously with the wafer load step (1) described above. That is, a wafer exchange step is configured by the steps (1) and (4).

[0011]

As described above, in the conventional projection exposure apparatus, the roughly classified three operations are repeatedly performed by using one wafer stage,

i.e., wafer exchange (including search alignment) → fine alignment → exposure → wafer exchange.

[0012]

Problems to Be Solved by the Invention

Because the above-mentioned projection exposure apparatus is mainly used as a mass producer of semiconductor elements or the like, it is necessarily required to improve a processing capability regarding how many wafers can be exposed in a certain time, i.e., the throughput.

[0013]

In this regard, in the present projection exposure apparatus, because the above-mentioned three operations are performed sequentially, it is required to reduce times necessary for the respective operations to improve the throughput. However, in the wafer exchange (including the search alignment), one operation is performed with respect to one wafer, so the effect of the improvement is relatively small. Furthermore, the time necessary for the fine alignment can be reduced by decreasing the number of the short sampling or reducing the measuring time of the short monolith when using the above-mentioned EGA system. However, because the alignment accuracy deteriorates, it is impossible to easily reduce the time necessary for the fine alignment.

[0014]

Thus, in conclusion, reduction in the time necessary for exposure is most effective in improving the throughput, but in the case of the stepper, the exposure operation includes the stepping time between the pure wafer exposure time and the shot. A high intensity of the light source is essential for the reduction of the exposure time of the wafer, but in this type of projection exposure apparatus, important conditions for this type of projection exposure apparatus other than those concerning the throughput described above include (1) resolution, (2) depth of focus (DOF: Depth of Focus), and (3) line width control accuracy or the like. Assuming that the exposure wavelength is λ, and the number of the aperture of the projection lens is N.A. (Numerical Aperture), the resolution R is proportional to λ /N.A., and the depth of focus (DOF) is proportional to $\lambda /(N.A.)^2$. For this reason, a light source having a short wavelength is required. The above-mentioned excimer laser is set to become mainstream in future, which fulfils both conditions of high power and short wavelength as compared with bright light or the like of a conventionally used super high pressure mercury lamp. As a result, a light source having a short wavelength and the high intensity of radiation suitable for a light source of the exposure apparatus is not considered at this stage. Thus, an improvement in throughput more than when the excimer laser is used as the light source is not particularly expected, and there is also a

limitation in an improvement in throughput due to the investigation of the light source.

[0015]

On the other hand, in order to reduce the stepping time between the shots, it is necessary to improve the maximum speed and the maximum acceleration of the stage for holding the wafer, but there was a problem in that the improvements in the maximum speed and the maximum acceleration easily cause deterioration of the positioning accuracy of the stage. In addition, in case of the scanning type projection exposure apparatus such as the step and scan system, the exposure time of the wafer can be reduced by increasing the relative scanning speed of the reticle and the wafer. However, because the improvement in relative scanning speed easily causes deterioration of the synchronization accuracy, it is impossible to easily increase the scanning speed. Thus, it is required to improve the controllability of the stage.

[0016]

However, in particular, in the apparatus that uses an off-axis alignment microscope, such as the projection exposure apparatus with the excimer laser light source which would be predominant in the future, it is not easy to improve the controllability of the stage. That is, in this type of projection exposure apparatus, in order to precisely control the position of the wafer stage, without Abbe's error, during exposure of the mask pattern via the projection optical system and during alignment, thereby to achieve highly precise superposition, it is necessary to set a configuration in which the measuring axis of the laser interferometer passes through the center of projection of the projection optical system and the center of detection of the alignment microscope. Furthermore, neither the measuring axis passing through the center of projection of the projection optical system nor the measuring axis passing through the center of detection of the alignment microscope should be interrupted in the movement range of the stage during exposure and in the movement range of the stage during alignment, and thus, the stage necessarily becomes large in size.

[0017]

As described above, in the method for reducing the time necessary for the respective operations of the above-mentioned three operations, it is difficult to improve the throughput without any demerit and the appearance of new technologies for improving the throughput by another method is desired.

[0018]

The present invention has been made under the circumstances as described above, and a first object of the invention is to provide an exposure method capable of improving throughput and determining the size of the substrate stage regardless of the baseline amount.

[0019]

Additionally, second to eleventh objects of the inventions are to provide an exposure apparatus capable of improving the throughput.

[0020]

Means to Solve Problems

If a plurality of actions among the above-mentioned three actions, i.e., wafer replacement (including search alignment), fine alignment and exposure, can be concurrently performed in parallel even partially, throughput may be improved compared with the sequential execution of these actions. The present invention has been made in this view and adopts the following methods and configurations. That is, according to claim 1of the present invention, there is provided an exposure method for exposing an image of a pattern formed on a mask (R) via a projection optical system (PL) onto the sensitive substrates (W), characterized by comprising: preparing two substrate stages (WS1 and WS2), each of which is movable independently in the same plane while holding a sensitive substrate (W); exposing the pattern image of the mask (R) on the sensitive substrate (W) held on one (WS1 or WS2) of the two substrate stages (WS1 and WS2) via the projection optical system (PL); measuring the positional relationship between an alignment mark on the sensitive substrate held on the other of the two substrate stages and a reference point on the other stage (WS2 or WS1) during exposure of the sensitive substrate (W) held on the one substrate stage (WS1 or WS2); detecting the positional deviation of the reference point on the other substrate stage (WS2 or WS1) from a predetermined reference point in a projection area of the projection optical system (PL) and the coordinate position of the other substrate stage, with the reference point on the other substrate stage being positioned in the projection area, after completion of exposure of the sensitive substrate held on the one substrate stage; and controlling the movement of the other substrate stage on the basis of the detected positional relationship, the detected positional deviation and the detected coordinate position to perform positional alignment between the sensitive substrate held on the other stage and the pattern image of the mask.

[0021]

According to such an exposure method, while the sensitive substrate (W) held on the one substrate stage (WS1 or WS2) of the two substrate stages (WS1 and WS2) is being exposed with the pattern image of the mask (R) via the projection optical system (PL), (1) the positional relationship between the alignment mark on the sensitive substrate (W) held on the other substrate stage (WS2 or WS1) of the two substrate stages and the reference point on the other stage (WS2 or WS1) is measured. As described above, the exposure action on the one substrate stage side and the alignment action on the other substrate stage side (measurement of the positional relationship between the alignment mark on the sensitive substrate held on the other substrate stage and the reference point on the other substrate stage) can be performed

in parallel. Thus, throughput can be improved in comparison with conventional technologies by which these actions were performed sequentially.

[0022]

After exposure of the sensitive substrate held on the one substrate stage is completed, (2) the positional deviation of the reference point on the other substrate stage (WS2 or WS1) from the predetermined reference point in the projection area of the projection optical system (PL) and (3) the coordinate position of the other substrate stage at the time of detecting the positional deviation are detected, with the reference point on the other substrate stage being positioned in the projection area. Then, the movement of the other substrate stage (WS2 or WS1) is controlled on the basis of (1) the detected positional relationship, (2) the detected positional deviation and (3) the detected coordinate position to perform alignment between the sensitive substrate held on the other stage and the pattern image of the mask.

[0023]

For this reason, it presents no disadvantages whether the interferometer (or coordinate system) for managing the position of the substrate stage at the time of detecting the positional relationship between the predetermined reference point on the other substrate stage of (1) and the alignment mark on the sensitive substrate is the same as or different from the interferometer (or coordinate system) for managing the position of the stage during the detection of the positional deviation and during the detection of the coordinate position of the substrate stage of (2) and (3). Thus, the alignment of the pattern image of the mask with the sensitive substrate placed on the other substrate stage can be performed highly accurately.

[0024]

Accordingly, when an off-axis alignment system is used as a mark detection system for detecting the alignment mark, for example, it becomes unnecessary to measure the positional relationship between the predetermined reference point in the projection area of the projection optical system (the center of projection of the pattern image of the mask) and the center of detection of the alignment system, that is, it is unnecessary to measure the baseline amount. As a result, whatever distance exists between the projection optical system and the alignment system produces no disadvantage. Thus, the size of the substrate stage can be designed irrespective of the baseline amount. Even if the substrate stage becomes small in size or light in weight, there is no disadvantage, and mask position measurement and patterning by exposure via the projection optical system can be carried out over the entire surface of the sensitive substrate. In this case, no influence is exerted by fluctuations in the baseline amount.

[0025]

According to the second aspect of the present invention, there is provided an exposure apparatus for exposing a pattern via a projection optical system (PL) onto the sensitive substrates (W), characterized by comprising: a first substrate stage (WS1) which is movable in a two-dimensional plane while holding a sensitive substrate (W); a second substrate stage (WS2) which is movable independently from the first substrate stage (WS1) in the same plane as that of the first substrate stage (WS1) while holding a sensitive substrate (W); an alignment system (WA), provided apart from the projection optical system (PL), for detecting the mark on the substrate stage (WS1 and WS2) or a mark on the sensitive substrate (W) held on the stage; an interferometer system (26) for measuring the two-dimensional positions of the first substrate stage and the second substrate stage; moving means (20, 22) for moving each of the two substrate stages between a predetermined first position in a stage movement range at the time of exposure during which the sensitive substrate held on the stage is exposed via the projection optical system, and a predetermined second position in a stage movement range at the time of alignment during which the mark on the stage or the mark on the sensitive substrate held on the stage is detected by the alignment system; and a controller (28) for controlling the actions of the two stages while monitoring the measured values of the interferometer system (26) so that during exposure of the sensitive substrate held on one of the first substrate stage and the second substrate stage, a mark detecting action by the alignment system (WA) is performed on the other of the first substrate stage and the second substrate stage, and then controlling the moving means (20, 22) to interchange the positions of the one substrate stage and the other substrate stage.

[0026]

According to the above, the controller (28) controls the actions of the two stages while monitoring the measured values of the interferometer system (26) so that during exposure of the sensitive substrate held on one stage, a mark detecting action by the alignment system (WA) is performed on the other stage, and then controls the moving means (20, 22) to interchange the position of the one substrate stage with the position of the other substrate stage. Thus, the parallel execution of the exposure action on the one substrate stage side and the alignment action on the other substrate stage side enables throughput to be improved. Also, if the sensitive substrate is replaced on the substrate stage at the second position after interchanging of the positions, actions of the two stages are interchanged, whereby during exposure of the sensitive substrate held on the other stage, a mark detecting action by the alignment system (WA) can be performed in parallel on the one stage.

[0027]

According to the third aspect of the present invention, in the exposure apparatus according to the second aspect, the interferometer system (26) has a first

measuring axis (Xe) and a second measuring axis (Ye) that intersect each other perpendicularly at the center of projection of the projection optical system (PL), and a third measuring axis (Xa) and a fourth measuring axis (Ya) that intersect each other perpendicularly at the center of detection of the alignment system (WA), and the controller (28) resets the measuring axes (Xe, Ye, Xa and Ya) of the interferometer system (26) when interchanging the positions of the one stage and the other stage.

[0028]

According to the above, the interferometer system (26) includes the first measuring axis (Xe) and the second measuring axis (Ye) that intersect each other perpendicularly at the center of projection of the projection optical system (PL), and the third measuring axis (Xa) and the fourth measuring axis (Ya) that intersect each other perpendicularly at the center of detection of the alignment system (WA). Thus, the positions of the substrate stages (WS1, WS2) can be managed precisely without Abbe's error both during exposure of the pattern onto the sensitive substrate via the projection optical system and during detection of the position detecting mark by the alignment system. Furthermore, the controller (28) resets the measuring axes (Xe, Ye, Xa and Ya) of the interferometer system (26) in interchanging the positions of the one stage and the other stage. Thus, during position interchange, even if the measuring axes of the interferometer system that has managed the positions of the substrate stages until then are interrupted, if the positions to reset the measuring axes (Xe, Ye, Xa and Ya) of the interferometer system (26) are set in the predetermined position in advance, after resetting, the positions of the first and second substrate stages can be managed using the measured values of the reset measuring axes.

[0029]

According to the fourth aspect of the present invention, there is provided an exposure apparatus for exposing a pattern on sensitive substrates (W) via a projection optical system (PL) which has a first substrate stage (WS1) which is movable in a two-dimensional plane while holding a sensitive substrate (W); a second substrate stage (WS2) which is movable independently from the first substrate stage (WS1) in the same plane as that of the first substrate stage while holding a sensitive substrate (W); an alignment system (WA), provided apart from the projection optical system (PL), for detecting a mark on the substrate stage or a mark on the sensitive substrate held on the stage; an interferometer system (26) for measuring the two-dimensional positions of the first substrate stage and the second substrate stage; moving means (20, 22) for moving each of the two substrate stages among three locations, i.e., a predetermined first position in a stage movement range at the time of exposure during which the sensitive substrate (W) held on the stage is exposed via the projection optical system (PL), a predetermined second position in a stage movement range at the time of alignment during which the mask on the stage or the mask on the sensitive

substrate held on the stage is detected by the alignment system (WA), and a third position at which the sensitive substrate is passed between the substrate stage and an external substrate carrier mechanism; and a controller (28) for controlling the two substrate stages (WS1 and WS2) and the moving means (20, 22) so that while the position of one of the first substrate stage (WA1) and second substrate stage (WS2) is managed by the interferometer system (26) and the sensitive substrate (W) held on the one stage is exposed with the pattern via the projection optical system (PL), the replacement of the sensitive substrate (W), and an alignment action for measuring the positional relationship between the alignment mark on the sensitive substrate (W) and a reference mask on the other stage based on the results of detection by alignment system (WA) and the measured values by the interferometer system (26) are sequentially performed on the other of the first and second substrate stages, and for controlling the two stages and the moving means so that after the actions on the two stages are both completed, the actions to be performed on the two stages are interchanged.

[0030]

According to the above, the controller controls the two substrate stages (WS1, WS2) and the moving means (20, 22) so that while the position of the one substrate stage is being managed by the interferometer system and the sensitive substrate held on the one substrate stage is being exposed with the pattern through the projection optical system, the replacement of the sensitive substrate (W), and an alignment action for measuring the positional relationship between the alignment point on the sensitive substrate (W) after replacement and the reference mark on the other stage based on the detection results of the alignment system (WA) and the measured values by the interferometer system (26) are sequentially performed on the other substrate stage. Since the exposure action on the one substrate stage side and the replacement of the sensitive substrate as well as the alignment action on the other stage side are thus performed in parallel, throughput can be further improved. In this case, since the sensitive substrate is replaced at the third position different from the first and second positions, the replacement can be performed at the position different from those of the alignment system and the projection optical system, whereby the disadvantage that the alignment system and the projection optical system impede the replacement of the sensitive substrate does not occur.

[0031]

Furthermore, the controller also controls the two stages and the moving means so that after the actions of the two stages are both completed, the actions to be performed on the two stages are interchanged. Thus, after completion of the actions on the two stages, the sensitive substrate held on the other stage is exposed

successively, and during this exposure, the mark detecting action by the alignment system (WA) can be performed on the one stage in parallel.

[0032]

In this case, an electronic lens barrel, for example, may be used as the projection optical system, and the pattern may be directly drawn on the sensitive substrate with an electron beam. However, as in the fifth aspect of the invention, a mask (R) with the pattern formed thereon may be further provided, and the pattern image formed on the mask (R) via the projection optical system (PL) may be projection-exposed onto the sensitive substrates (W) on the first substrate stage (WS1) and the second substrate stage (WS2).

[0033]

According to the sixth aspect of the present invention, in the exposure apparatus according to the fifth aspect, the interferometer system (26) has a first measuring axis (Xe) and a second measuring axis (Ye) that intersect each other perpendicularly at the center of projection of the projection optical system (PL), and a third measuring axis (Xa) and a fourth measuring axis (Ya) that intersect each other perpendicularly at the center of detection of the alignment system (WA), and the controller (28) resets the first and second measuring axes (Xe and Ye) of the interferometer system (26) in moving each of the two stages to the first position, and resets the third and fourth measuring axes (Xa and Ya) of the interferometer system (26) in moving each of the two stages (WS1 and WS2) to the second position.

[0034]

According to the above, since the interferometer system (26) has the first measuring axis (Xe) and the second measuring axis (Ye) intersecting each other perpendicularly at the center of projection of the projection optical system (PL), and the third measuring axis (Xa) and the fourth measuring axis (Ya) intersecting each other perpendicularly at the center of detection of the alignment system (WA), the positions of the substrate stages (WS1, WS2) can be managed precisely without Abbe's error both during exposure of the pattern onto the sensitive substrate via the projection optical system and during detection of the position detecting mark by the alignment system. Furthermore, the controller (28) resets the first and second measuring axes (Xe and Ye) of the interferometer system (26) in moving each of the two stages (WS1, WS2) to the first position, and resets the third and fourth measuring axes (Xa and Ya) of the interferometer system (26) in moving each of the two stages (WS1, WS2) to the second position. Thus, prior to the start of exposure and the start of aligning measurement for each substrate stage, it is possible to rest the measuring axes that are required for the respective actions. Until then, even if the measuring axes of the interferometer system that has managed the positions of the respective substrate stages are interrupted, after resetting, the positions of the two stages at the

time of exposure and alignment can be managed using the measured values of the reset measuring axes.

[0035]

In this case, as in the seventh aspect of the present invention, it is desirable to further provide a mark position detector (52A, 52B) for detecting the relative positional relationship between the center of projection of the pattern image of the mask (R) formed by the projection optical system and the reference point on the stage via the mask (R) and the projection optical system (PL). In this case, the positional relationship between the center of projection of the pattern image of the mask (R) and the reference point on the substrate stage can be detected by the mark position detector (52A, 52B) via the mask (R) and the projection optical system (PL), when the substrate stages (WS1, WS2) are positioned at a position at which the positional relationship between the predetermined reference point on the substrate stage (18) and the center of projection of the mask pattern image can be detected in the projection area of the projection optical system (PL). In this case, it is desirable that the position at which the positional relationship between the predetermined reference point on the substrate stage (18) and the center of projection of the mask pattern image can be detected in the projection area of the projection optical system (PL) be set as the first position, and the first and second measuring axes be reset at this position.

[0036]

In the respective aspects of the invention, as in the eighth aspect, each of the substrate stages (WS1, WS2) may have stage bodies (WS1a, WS2a), and substrate holding members (WS1b, WS2b) detachably mounted on the bodies (WS1a, WS2a) for holding the substrate, a reflection surface for an interferometer may be provided on the side surfaces of the substrate holding members (WS1b, WS2b), and reference marks (WM, RM) may be formed on the upper surface of the substrate holding member. When the exposure apparatus has such a formation, the moving means (20, 22) may move the substrate holding member among the respective locations mentioned earlier instead of the substrate stage.

[0037]

In the above cases, the moving means may be of any type which moves the substrate stage or the substrate holding member among the three locations, i.e., the first position, the second position and the third position (or between the first and second positions), without monitoring the measured values by the interferometer. For instance, as in the present invention, the moving means may include robot arms (20, 22).

[0038]

Furthermore, in the respective aspects of the invention, a fixed mirror serving as a reference for measurement by the interferometer system may be located at any

place. However, as in the tenth aspect of the invention, fixed mirrors (14X, 14Y, 18X and 18Y) serving as a reference for measurement by the interferometer may be attached to the projection optical system (PL) and the alignment system (WA), respectively. In this case, as compared with the fixed mirrors existing at other places, errors minimally occur in the results of measurement under the influence of positional changes of the fixed mirrors over time or the influence of positional changes of the fixed mirrors associated with vibrations of the apparatus.

[0039]

In the respective aspects of the invention, only two stages, i.e., the first substrate stage and the second substrate stage, are provided. However, as in the first aspect, at least one other substrate stage movable independently of the two substrate stages in the same plane as those of two stages while holding a sensitive substrate may be further provided in addition to the first substrate stage (WS1) and the second substrate stage (WS2).

[0040]

Embodiments

[First Embodiment]

A first embodiment of the present invention will now be described with reference to FIGS. 1 to 4.

[0041]

FIG. 1 shows the configuration of an exposure apparatus 100 according to the first embodiment. This exposure apparatus 100 is a step-and-repeat type reduced projection exposure apparatus (a so-called stepper).

[0042]

The projection exposure apparatus 100 includes an illumination system IOP, a reticle stage RST for holding a reticle R as a mask, a projection optical system PL for projecting the image of a pattern formed in the reticle R onto a wafer W as a sensitive substrate, a wafer stage WS1 as a first substrate stage movable on a base 12 in a two-dimensional direction XY while holding the wafer W, a wafer stage WS2 as a second substrate stage movable on the base 12 in the two-dimensional direction XY independently of the wafer stage WS1 while holding the wafer W, an interferometer system 26 for measuring the respective positions of the two wafer stages WS1, WS2, and a main control device 28 as a controller having a minicomputer (or a microcomputer) including a CPU, a ROM, a RAM, an I/O interface or the like for supervising and controlling the entire apparatus.

[0043]

The illumination system IOP is constituted by a light source (a mercury lamp or an excimer laser), and an illumination optical system including a fly eye lens, a relay lens, a condenser lens or the like. This illumination system IOP illuminates a

pattern of the lower surface of the reticle R (pattern formation surface) with a uniform illuminance distribution by illumination light IL for exposure from the light source. The illumination light IL for exposure used is an emission line such as an i-line from a mercury lamp, or excimer laser light from such as KrF or ArF.

[0044]

On the reticle stage RST, the reticle R is fixed via fixing means (not shown). The reticle stage RST is finely drivable by a driving system (not shown) in an X-axis direction (the direction perpendicular to the sheet face of FIG. 1), a Y-axis direction (the left and right direction of the sheet face of FIG. 1), and θ direction (the direction of rotation in the XY plane). This enables the reticle stage RST to perform positioning of the reticle R (reticle alignment) such that the center of the pattern of the reticle R (the reticle center) can substantially agree with the optical axis Ae of the projection optical system PL. In FIG. 1, the state in which this reticle alignment has been performed is illustrated.

[0045]

The projection optical system PL has the optical axis Ae lying in a Z-axis direction perpendicular to the moving plane of the reticle stage RST. Here, a both-sided telecentric system with a predetermined reduction ratio β (β is, for example, 1/5) is used. Thus, when the reticle R is illuminated at a uniform illuminance by the illumination light IL with the pattern of the reticle R being aligned with the shot areas on the wafer W, the pattern on the pattern formation surface is reduced by the projection optical system PL at the reduction ratio β. The reduced pattern is projected onto the wafer W coated with a photoresist, whereby the reduced image of the pattern is formed in each shot area on the wafer W.

[0046]

In the present embodiment, an X fixed mirror 14X serving as a reference for X-axis direction position control during exposure of the wafer stages WS1, WS2 is fixed to one side (left side in FIG. 1) surface of the projection optical system PL in the X-axis direction. Similarly, a Y fixed mirror 14Y serving as a reference for Y-axis direction position control during exposure of the wafer stages WS1, WS2 is fixed to one side (rear side of the sheet face of FIG. 1) surface of the projection optical system PL in the Y-direction (see FIG. 3).

[0047]

On the bottom surface of each of the wafer stages WS1, WS2, a gas static pressure bearing (not shown) is provided. By these gas static pressure bearings, the wafer stages WS1, WS2 are supported floatingly above the base 12 with a clearance of about several microns kept between them and the upper surface of the base 12. One side (left side in FIG. 1) surface in the X-axis direction of each of the wafer stages WS1, WS2, and one side (rear side of the sheet face in FIG. 1) surface in the Y-

axis direction of each of the wafer stages WS1, WS2 are mirror-finished to form reflecting surfaces that function as moving mirrors for reflecting a measuring beam from the interferometer system 26.

[0048]

Onto the bottom surfaces of the wafer stages WS1, WS2, magnets are fixed respectively. Under an electromagnetic force generated by driving coils (not shown) embedded in predetermined ranges of the base (specifically, a predetermined region near a site below the projection optical system PL, and a predetermined region near a site below the alignment microscope WA), the wafer stages WS1, WS2 are moved on the base 12 in the two-dimensional direction XY. That is, the magnets on the bottom surfaces of the wafer stages WS1, WS2 and the driving coils embedded in the base 12 form a so-called moving magnet type linear motor as driving means for the wafer stages WS1, WS2. The driving current of the driving coils of this linear motor is controlled by the main control device 28.

[0049]

On the wafer stages WS1, WS2, wafers W are held by vacuum suction or the like via wafer holders (not shown). Onto the wafer stages WS1, WS2, reference mark plates FM1, FM2 whose surfaces are as high as the surface of the wafer W are fixed. On the surface of the reference mark plate FM1, as shown in the plan view of FIG. 2, a mark WM for measurement with a wafer alignment microscope WA to be described later on is formed at the center in the longitudinal direction of the surface. On both sides of the mark WM in the longitudinal direction, a pair of marks RM is formed for use in measuring the relative positional relationship with the reticle R via the projection optical system PL. On the other reference mark plate FM2, exactly the same marks WM, RM are formed.

[0050]

Furthermore, in the present embodiment, an off-axis alignment microscope WA as an alignment system for detecting a position detecting mark (alignment mark) formed on the wafer W is provided at a predetermined distance of, e.g., 3,000 mm from the objection optical system PL in a direction at an angle of nearly 45 ° to the XY axis. The wafer W has level differences formed by exposure and processing of the previous layers. They include position detecting marks (alignment marks) for measurement of the positions of shot areas on the wafer. These alignment marks are measured by the alignment microscope WA.

[0051]

The alignment microscope WA used here is an FIA (field image alignment) type alignment microscope based on image processing. According to this microscope, illumination light emitted from a light source (not shown) which produces broad band illumination light, such as a halogen lamp, is radiated on the wafer W (or the

reference mark plate FM) after passing an objective lens (not shown). Reflected light from a wafer mark region (not shown) on the surface of the wafer W passes sequentially through the objective lens and an indicator plate (not shown), forming an image of the wafer mark and an image of the indicator on the indicator plate on an imaging surface of a CCD or the like (not shown). Photoelectric conversion signals of these images are processed by a signal processing circuit (not shown) in a signal processing unit 16. The relative positional relationship between the wafer mark and the indicator is calculated by a computing circuit (not shown), and this relative positional relationship is conveyed to the main control device 28. The main control device 28 calculates the position of the alignment mark on the wafer W on the basis of the relative positional relationship and the measured values of the interferometer system 26.

[0052]

To one side (left side in FIG. 1) surface of the alignment microscope WA in the X-axis direction, an X fixed mirror 18X is fixed for serving as a reference for position control in the X-axis direction during the alignment action of the wafer stages WS1, WS2. Similarly, to one side (rear side of the sheet face of FIG. 1) surface of the alignment microscope WA in the Y-axis direction, a Y fixed mirror 18Y is fixed for serving as a reference for position control in the Y-axis direction during the exposure action of the wafer stages WS1, WS2.

[0053]

Furthermore, the alignment microscope is not limited to a FIA type, but other optical alignment devices such as LIA (Laser Interferometric Alignment) or LSA (Laser Step Alignment) devices, other optical devices such as a phase contrast microscope and a differential interference microscope, and non-optical devices such as STM (Scanning Tunnel Microscope) for detecting the atomic-level irregularities of the surface of a specimen by utilizing the tunnel effect, and AFM (Atomic Force Microscope) for detecting the atomic- and molecular-level irregularities of the surface of a specimen by utilizing atomic force (gravity and repulsion) can be used.

[0054]

In the projection exposure apparatus 100 of the present embodiment, reticle alignment microscopes 52A, 52B as a mark detecting system for simultaneously observing an image of the reference mark RM on the reference mark plate FM and a reticle alignment mark (not shown) on the reticle R via the projection optical system PL are provided above the reticle R. Detection signals S1, S2 from the reticle alignment microscopes 52A, 52B are supplied to the main control device 28. In this case, deflecting mirrors 54A, 54B for guiding detection light from the reticle R to the reticle alignment microscopes 52A, 52B are unitized integrally with the relevant reticle alignment microscopes 52A, 52B to configure a pair of microscope units 56A,

56B. Upon start of an exposure sequence, these microscope units 56A, 56B are retreated by a mirror driving device (not shown) to positions beyond the reticle pattern surface under a command from the main control device 28.

[0055]

Next, the interferometer system 26 of FIG. 1 which manages the positions of the wafer stages WS1, WS2 will be described in detail.

[0056]

This interferometer system 26, actually, includes a first laser interferometer 26Xe for X-axis direction position measurement, a second laser interferometer 26Ye for Y-axis direction position measurement, a third laser interferometer 26Xa for X-axis direction position measurement, and a fourth laser interferometer 26Ya for Y-axis direction position measurement, as illustrated in FIG. 3. These components are representatively shown in FIG. 1 as the interferometer system 26.

[0057]

The first laser interferometer 26Xe projects onto the X fixed mirror 14X a reference beam X_{e1} in the X-axis direction that passes through the center of projection of the projection optical system PL. The first laser interferometer 26Xe also projects a measuring beam X_{e2} onto the reflecting surface of the wafer stage (WS1 or WS2). Reflected light waves from these two beams are superposed into one for interference. Based on this interference state, the displacement of the reflecting surface of the wafer stage relative to the fixed mirror 14X is measured.

[0058]

The second laser interferometer 26Ye projects onto the Y fixed mirror 14Y a reference beam Y_{e1} in the Y-axis direction that passes through the center of projection of the projection optical system PL. The second laser interferometer 26Ye also projects a measuring beam Y_{e2} onto the reflecting surface of the wafer stage (WS1 or WS2). Reflected light waves from these two beams are superposed into one for interference. Based on this interference state, the displacement of the reflecting surface of the wafer stage relative to the fixed mirror 14Y is measured.

[0059]

The third laser interferometer 26Xa projects onto the X fixed mirror 18X a reference beam X_{a1} in the X-axis direction that passes through the center of detection of the alignment microscope WA. The third laser interferometer 26Xa also projects a measuring beam X_{a2} onto the reflecting surface of the wafer stage (WS1 or WS2). Reflected light waves from these two beams are superposed into one for interference. Based on this interference state, the displacement of the reflecting surface of the wafer stage relative to the fixed mirror 18X is measured.

[0060]

The fourth laser interferometer 26Ya projects onto the Y fixed mirror 18Y a reference beam Y_{a1} in the Y-axis direction that passes through the center of detection of the alignment microscope WA. The fourth laser interferometer 26Ya also projects a measuring beam Y_{a2} onto the reflecting surface of the wafer stage (WS1 or WS2). Reflected light waves from these two beams are superposed into one for interference. Based on this interference state, the displacement of the reflecting surface of the wafer stage relative to the fixed mirror 18Y is measured.

[0061]

Here, the measuring axis of the first laser interferometer 26Xe that includes the reference beam X_{e1} and the measuring beam X_{e2} is called the first measuring axis Xe. The measuring axis of the second laser interferometer 26Ye that includes the reference beam Y_{e1} and the measuring beam Y_{e2} is called the second measuring axis Ye. The measuring axis of the third laser interferometer 26Xa that includes the reference beam X_{a1} and the measuring beam X_{a2} is called the third measuring axis Xa. The measuring axis of the fourth laser interferometer 26Ya that includes the reference beam Y_{a1} and the measuring beam Y_{a2} is called the fourth measuring axis Ya. The first measuring axis Xe and the second measuring axis Ye intersect each other perpendicularly at the center of projection of the projection optical system PL (consistent with the center of the optical axis Ae), while the third measuring axis Xa and the fourth measuring axis Ya intersect each other perpendicularly at the center of detection of the alignment microscope WA. Because of this configuration, the position of the wafer stage can be measured precisely in the direction of each measuring axis, without Abbe's error due to yawing or the like of the wafer stage, both during measurement of the position detecting mark on the wafer W (alignment mark) and during exposure of the wafer W with the pattern. To raise the accuracy of measurement, it is more desirable to use two-frequency heterodyne interferometers as the above first to fourth laser interferometers.

[0062]

Returning to FIG. 1, the measured values of the interferometer system 26 are supplied to the main control device 28. The main control device 28 controls the positions of the wafer stages WS1, WS2 via the aforementioned linear motors while monitoring the measured values of the interferometer system 26.

[0063]

As is clear also from FIG. 3, the present first embodiment is configured such that during the exposure of the wafer W on the wafer stage WS1 or WS2 with the reticle pattern through the projection optical system PL, the position of the wafer stage is managed by the first and second laser interferometers 26Xe, 26Ye. During the measurement of the position detecting mark on the wafer W (alignment mark) by the alignment microscope WA, on the other hand, the position of the wafer stage is

managed by the third and fourth laser interferometers 26Xa, 26Ya. After completion of the exposure, or after completion of the alignment mark measurement, however, each measuring axis does not hit the reflecting surface of each wafer stage. Thus, the positional control of the wafer stage by the interference system 26 becomes difficult.

[0064]

The projection exposure apparatus 100 of the present embodiment, therefore, has a first robot arm 20 as a moving means for freely moving the wafer stage WS1 among three locations, i.e., a third position indicated by a virtual line in FIG. 3, a second position indicated by a solid line in FIG. 3, and a first position at which the wafer stage WS2 is located in FIG. 3; and a second robot arm 22 as a moving means for freely moving the wafer stage WS2 similarly among the three locations, the first position, the second position and the third position. These first and second robot arms 20, 22 are also controlled by the main control device 28, and the wafer stage position control accuracy of these first and second robot arms 20, 22 is generally about ±1 μm. As these robot arms 20, 22, articulated robot arms of a known configuration are used, and their detailed description is omitted. To realize that position control accuracy without fail, upward/downward moving pins as illustrated by the numerals 24A, 24B in FIG. 3 may be provided as stoppers.

[0065]

A brief explanation for the third, second and first positions will be given here. The third position refers to a wafer replacement position at which the wafer W is passed on between a carrier arm 50 configuring part of an external substrate carrier mechanism and the wafer stage (WS1, WS2). The second position refers to a position at which the alignment of the wafer W on the wafer stage is performed after loading of the wafer W is completed, and also an arbitrary position at which the third measuring axis Xa and the fourth measuring axis Ya both hit the reflecting surfaces of the wafer stage. The first position refers to a position at which the exposure of the wafer W on the wafer stage is performed after alignment of the wafer is completed, and also an arbitrary position at which the first measuring axis Xe and the second measuring axis Ye both hit the reflecting surfaces of the wafer stage.

[0066]

In the present embodiment, as described above, the positions illustrated in FIG. 3 are determined as the first, second and third positions. However, the second position may be any position if it satisfies the above-mentioned definition. For example, a position at which the mark WM on the reference mark plate FM rests in the detection area of the alignment microscope WA may be set as the second position. Likewise, the first position may be any position if it satisfies the above-mentioned definition. For example, a position at which the mark RM on the reference mark plate

FM rests in the projection area of the projection optical system PL may be set as the first position.

[0067]

The following is an explanation of the overall flow of actions of the projection exposure apparatus 100 of the present embodiment constructed as stated above.

[0068]

(1) Assume that the wafer stage WS1 lies at the third position, and the wafer stage WS2 lies at the first position.

[0069]

First of all, wafer replacement is performed between the wafer stage WS1 and the carrier arm 500. This wafer replacement is carried out by a center up (wafer-up mechanism) mechanism above the wafer stage WS1 and the carrier arm 50 as done in the above-mentioned embodiment. Thus, a detailed description is omitted. As stated previously, the positioning accuracy of a robot arm is generally abut ±1 μm or less, so that the positioning accuracy of the carrier arm 50 is also comparable to this value. Prior to this wafer replacement, the wafer W has roughly been positioned by a prealignment device (not shown) in the directions of X, Y and θ. Thus, its position of loading on the wafer stage does not deviate markedly. The loading position of the wafer W relative to the reference mark plate FM1, for example, is within the error of ±1 μm or less.

[0070]

During the wafer replacement, the wafer stage WS1 is not position-controlled by a laser interferometer. However, the first robot arm 20 grasps the wafer stage WS1, so that the disadvantage of the wafer stage WS1 moving about does not occur. During the grasping by the first robot arm 20, the linear motor that drives the wafer stage WS1 is at a halt (the same holds in the following description).

[0071]

Upon completion of wafer replacement (loading of the wafer W onto the wafer stage WS1), the main control device 28 controls the first robot arm 20 to move the wafer stage WS1 to the second position indicated by the solid line in FIG. 3. At this position, the main control device 28 resets the third and fourth laser interferometers 26Xa, 26Ya simultaneously. Upon completion of this resetting, the first robot arm 20 finishes its role. Thus, the first robot arm 20 is retreated, away from the wafer stage WS1, by a drive system (not shown) to a non-interfering position in accordance with a command from the main control device 28.

[0072]

After resetting of the third and fourth laser interferometers 26Xa, 26Ya is completed, the main control device 28 controls the wafer stage WS1 via the aforementioned linear motor, while monitoring the measured values of the

interferometers 26Xa, 26Ya, so that the mark WM on the reference mark plate FM1 on the wafer stage WS1 is positioned in the detection area of the alignment microscope WA. The accuracy of positioning to the second position by the first robot arm 20 can be generally about ±1 μm or less, as stated earlier. Since the interferometric measuring axes have been reset at this second position, position control can be performed afterwards with a resolving power of about 0.01 μm on the basis of the design value (the relative positional relationship in design between the reflecting surface of the wafer stage WS1 and the mark WM on the reference mark plate). As a result, the wafer stage WS1 is positioned with sufficient accuracy for measurement of the mark WM by the alignment microscope WA. When the second position is set at a position at which the mark WM on the reference mark plate FM1 on the wafer stage WS1 is positioned in the detection area of the alignment microscope WA, the movement of the wafer stage WS1 after resetting of the interferometers is not necessary. This is more desirable from the aspect of throughput.

[0073]

Then, the alignment microscope WA measures the position of the mark WM (ΔW_X, ΔW_Y) on the reference mark plate FM1 relative to the center of detection (center of indicator) of the alignment microscope WA. The main control device 28 obtains the average values (X_0, Y_0) of the measured values of the third and fourth laser interferometers 26Xa, 26Ya during this measurement. The outcome shows that when the measured values of the laser interferometers 26Xa, 26Ya show ($X_0 - \Delta W_X$, $Y_0 - \Delta W_Y$), the mark WM on the reference mark plate FM1 lies directly below the center of detection (center of indicator) of the alignment microscope WA. A series of actions of the third and fourth laser interferometers 26Xa, 26Ya will be called W-SET in the following description.

[0074]

While wafer replacement, interferometer resetting, and a series of actions of the W-SET are being performed on the one wafer stage, WS1, in the above manner, the actions described below are carried out on the other wafer stage, WS2.

[0075]

That is, the wafer stage WS2 is moved to the first position by the second robot arm 22 as described previously. The control for positioning to the first position is also performed with an accuracy of ±1 μm or less. At the same time that the movement of the wafer stage WS2 to the first position is completed, the main control device 28 resets the first and second laser interferometers 26Xe, 26Ye.

[0076]

Upon completion of this resetting by the first and second laser interferometers 26Xe, 26Ye, the second robot arm 22 finishes its role. Thus, the second robot arm is

retreated, away from the wafer stage WS2, by a drive system (not shown) to a non-interfering position in accordance with a command from the main control device 28.

[0077]

Then, the main control device 28 controls the position of the wafer stage WS2 via the linear motor, while monitoring the measured values of the laser interferometers 26Xe, 26Ye, so that the mark RM on the reference mark plate FM2 is positioned at a position at which it overlaps via the projection optical system PL the reticle alignment mark (not shown) formed on the reticle R in the projection area of the projection optical system. In this case, the accuracy of positioning to the first position by the second robot arm 22 can be generally about ±1 μm or less, as stated earlier. Since the interferometric measuring axes have been reset at this first position, position control can be performed afterwards with a resolving power of about 0.01 μm on the basis of the design values (the relative positional relationship in design between the reflecting surfaces of the wafer stage WS2 and the marks RM on the reference mark plate FM2). As a result, the wafer stage WS2 is positioned with necessary and sufficient accuracy for the simultaneous observation of the reticle alignment mark and the mark RM on the reference mark plate FM by the reticle alignment microscopes 52A, 52B.

[0078]

Then, the reticle alignment microscopes 52A, 52B measure the relative spacings (ΔRX, ΔRY) between the reticle alignment mark on the reticle R and the mark RM on the reference mark plate FM2, namely, the positional deviations (ΔRX, ΔRY) of the center of the reference mark RM as the reference point on the wafer stage WS2 from the center of projection of the pattern image of the reticle R as the predetermined reference point in the projection area of the projection optical system PL. The main control device 28 takes in these measured values of the reticle alignment microscopes 52A, 52B, and simultaneously reads the measured values (X_1, Y_1) of the laser interferometers 26Xe, 26Ye. The results show that the positions at which the measured values of the laser interferometers 26Xe, 26Ye become (X_1 - ΔR_X, Y_1 - ΔR_Y) are the positions at which the reticle alignment mark and the mark RM on the reference mark plate FM2 just overlap each other via the projection optical system PL. This series of actions after resetting of the first and second laser interferometers 26Xe, 26Ye will be called R-SET in the following description.

[0079]

(2) Then, wafer alignment on the wafer stage WS1 side and exposure on the wafer stage WS2 side are performed in parallel.

[0080]

After resetting of the third and fourth laser interferometers 26Xa, 26Ya, the position of the wafer stage WS1 is managed based on the measured values of the laser

interferometers 26Xa, 26Ya. The main control device 28 measures the positions of the position detecting marks (alignment marks) for predetermined specific sample shots among a plurality of shot areas on the wafer W. The main control device 28 measures these positions on the (Xa, Ya) coordinate system based on output from the alignment microscope WA, by moving the wafer stage WS1 sequentially via the linear motor, while monitoring the measured values of the interferometers 26Ya, 26Xa. In this case, the measured values of the interferometers ($X_0 - \Delta_X$, $Y_0 - \Delta_Y$) when the mark WM on the reference mark plate FM1 comes directly below the center of detection of the alignment microscope WA have been obtained. Based on these values and the design values for the relative positions of each alignment mark to the reference mark WM, it is determined by computation what the measured values of the laser interferometers 26Ya, 26Xa should be in order to position each alignment mark on the wafer W in the detection area of the wafer alignment microscope WA, and what position the wafer stage WS1 should be moved to in order to achieve those values. Based on the results of these computations, the wafer stage WS1 is moved sequentially.

[0081]

To position the wafer W in the directions of X, Y and θ, it suffices to measure, at least, two X measurement marks and one Y measurement mark (or one X measurement mark and two Y measurement marks). Here, three or more X measurement marks not on a straight line, and three or more Y measurement marks not on a straight line should be measured as EGA sample shots.

[0082]

The measured alignment mark (wafer mark) positions of the respective sample shots and the data on arrangement of the designed shot areas are used to perform statistical calculation by the least-squares method as disclosed in Japanese Unexamined Patent Application Publication No. 61-44429, thereby obtaining all data on the arrangement of the plurality of shot areas on the wafer W. However, it is desirable to subtract from the results of calculation the aforementioned value of the interferometers ($X_0 - \Delta_X$, $Y_0 - \Delta_Y$), which is obtained when the mark WM on the reference mark plate FM1 comes directly below the center of detection of the alignment microscope WA, so as to convert into data relative to the reference mark WA on the reference mark plate FM1. This measure gives a necessary and sufficient knowledge of the relative positional relationship between the mark WM on the reference mark plate FM1 and the reference point of each shot area on the wafer W.

[0083]

In parallel with the fine alignment (EGA) on the wafer stage WS1 side, superposed exposure of the pattern image of the reticle R and a known pattern of shot

areas on the wafer W is performed on the wafer stage WS2 side in the following manner:

[0084]

That is, the main control device 28 positions each shot area on the wafer W in the exposure position, while monitoring the measured values of the interferometers 26Ye, 26Xe, based on the results of measurement of the positional deviations, the coordinate position (Xe, Ye) of the wafer stage WS2 at that time, and the coordinate data on the arranged shots relative to the reference mark WA on the reference mark plate FM2 calculated in the same way as in the alignment action. Performing this positioning, the main control device 28 exposes the wafer W with the reticle pattern sequentially in the step-and-repeat manner, while controlling the opening and closing of the shutter in the illumination optical system. Here, high precision superposition is possible although the interferometers 26Xe, 26Ye are reset (the measuring axes of the interferometers are interrupted) prior to the exposure of the wafer W on the wafer stage WS2. Detailed reasons for this are as follows: The spacing between the mark WM and the mark RM on the reference mark plate FM2 is known. As a result of fine alignment (EGA) performed previously, the relative positional relationship between the mark WM on the reference mark plate FM2 and the reference point of each shot area on the wafer W has been calculated in the same manner as described earlier. Also, it has been measured where on the wafer stage WS2 the reticle alignment mark on the reticle R is situated (namely, what is the relative positional relationship between the center of projection of the pattern image of the reticle (almost consistent with the center of projection of the projection optical system PL) as the predetermined reference point in the projection area of the projection optical system PL and the mark RM as the reference point on the wafer stage WS2). Based on the results of these measurements, it is clear what measured values of the first and second laser interferometers 26Xe, 26Ye result in the exact superposition of the pattern image of the reticle R with each shot area on the wafer W.

[0085]

(3) As described above, fine alignment (EGA) is completed on the wafer stage WS1 side, while exposure with the reticle pattern for all the shot areas on the wafer W is completed on the wafer stage WS2 side. Then, the wafer stage WS1 is moved to the first position below the projection optical system PL, while the wafer stage WS2 is moved to the third position, the position of wafer replacement.

[0086]

That is, the wafer stage WS1 is grasped by the first robot arm 20 and moved to the first position in accordance with an instruction from the main control device 28. The control for positioning to the first position is performed with an accuracy of ±1 μm or less. Simultaneously with the completion of movement of the wafer stage WS1

to the first position, the main control device 28 resets the first and second laser interferometers 26Xe, 26Ye.

[0087]

Upon completion of this resetting, the first robot arm 20 finishes its role. Thus, the first robot arm 20 is retreated, away from the wafer stage WS1, by the drive system (not shown) to a non-interfering position in accordance with an instruction from the main control device 28.

[0088]

Then, the main control device 28 carries out R-SET in the same manner as the wafer stage WS2 side stated earlier. This step results in the measurement of the relative gaps (ΔR_X, ΔR_Y) between the reticle alignment mark and the mark RM on the reference mark plate FM1, namely, the positional deviations (ΔR_X, ΔR_Y) of the center of the reference mark RM as the reference point on the wafer stage WS2 from the center of projection of the pattern image of the reticle R as the predetermined reference point in the projection area of the projection optical system PL, as well as the stage coordinate position (X_1, Y_1) at the time of measuring the positional deviations.

[0089]

While the interferometer resetting and the R-SET are being performed on the wafer stage WS1 side in the above manner, the second robot arm 22 grasps the wafer stage WS2, whose exposure action has been completed, in accordance with an instruction from the main control device 28. The second robot arm 22 moves this wafer stage WS2 to the wafer passing-on position (third position) for wafer replacement. Then, wafer replacement, interferometer resetting and W-SET are performed in the same manner as on the wafer stage WS1 side that has been mentioned previously.

[0090]

(4) Then, the main control device 28, as stated earlier, controls the actions of the wafer stages WS1 and WS2 so that fine alignment (EGA) is performed on the wafer stage WS2 side, while the wafer W is sequentially exposed with the reticle pattern by the step-and-repeat method on the wafer stage WS1 side in parallel with EGA.

[0091]

(5) Thereafter, the main control device 28 controls the actions of the stages WS1, WS2 and the actions of the first and second robot arms so that the actions of (1) to (4) explained above will be repeated in sequence.

[0092]

A flow of the above-described parallel actions taking place on the two stages, WS1 and WS2, is illustrated in FIG. 4.

[0093]

As described above, the projection exposure apparatus 100 according to the first embodiment can perform an exposure action on one of the wafer stage WS1 and the wafer stage WS2, and a fine alignment action on the other stage in parallel. Thus, throughput can be expected to improve markedly in comparison with earlier technologies by which wafer replacement (including the search alignment), fine alignment and exposure were performed sequentially. In general, this is because a fine alignment action and an exposure action account for a high proportion of the time required for an exposure sequence.

[0094]

The above embodiment also makes it a precondition that the measuring axes of the interferometer system 26 are interrupted. Thus, it suffices for the reflecting surface (a moving mirror, if any) of each wafer stage to be slightly longer than the wafer diameter. Compared with earlier technologies requiring uninterrupted measuring axes, therefore, the wafer stage can be compact and lightweight, so that an improvement in stage controlling performance can be expected.

[0095]

The embodiment, moreover, makes it a precondition that the measuring axes of the interferometer system are interrupted, and the position of the mark on the reference mark plate FM on the stage is measured each before alignment and exposure. Thus, it produces no disadvantage however long the center distance (baseline amount) between the center of projection of the projection optical system PL and the center of detection of the alignment microscope WA will be. By providing a somewhat large spacing between the projection optical system PL and the alignment microscope WA, wafer alignment and exposure can be performed in a time-parallel manner, with no interference between the wafer stage WS1 and the wafer stage WS2.

[0096]

In the above embodiment, furthermore, the interferometer system 26 has the first measuring axis Xe and the second measuring axis Ye intersecting perpendicularly at the center of projection of the projection optical system PL, and the third measuring axis Xa and the fourth measuring axis Ya intersecting perpendicularly at the center of detection of the alignment system WA. Thus, the two-dimensional position of the wafer stage can be managed accurately both during an alignment action and during exposure.

[0097]

In addition, the fixed mirrors 14X, 14Y, 18X and 18Y for interferometers are fixed to the side surfaces of the projection optical system PL and the side surfaces of the alignment microscope WA. Unless the positions of the fixed mirrors change during alignment and exposure, therefore, disadvantages, such as a fall in the position

control accuracy of the wafer stage, will not emerge, even if the positions of the fixed mirrors change owing to changes over time or vibrations of the apparatus. Thus, constructing the alignment microscope WA so as to be movable upward and downward would not cause any disadvantage.

[0098]

The foregoing first embodiment has been described such that the wafer stages WS1 and WS2 are moved by the first and second robot arms 20, 22 among three locations, i.e., the first, second and third positions. However, the present invention is in no way limited to this configuration. If the wafer is replaced at the second position, for example, the wafer stages WS1 and WS2 may be moved by the first and second robot arms 20, 22 between the first and second positions. In this case, the main control device 28 controls the actions of the wafer stages WS1 and WS2 so that an exposure action for the wafer W on one of these stages and an alignment action for the wafer W on the other stage are performed in parallel. Then, the main control device 28 causes the first and second robot arms 20, 22 to interchange the positions of both stages.

[0099]

The first embodiment has also been described such that step-and-repeat type exposure is performed for the wafer W on the stage on the basis of EGA. However, the present invention is in no way limited to this configuration, and the pattern image of the reticle may be projected sequentially onto each shot area on the wafer W with alignment and exposure being repeated die-by-die. In this case, the relative position of each alignment mark relative to the mark WM formed on the reference mark plate FM on the stage is measured during alignment. Thus, the reticle pattern image can be superimposed on each shot area based on this relative position in the same manner as described above. Such a die-by-die method is desirably adopted when the number of the shot areas on the wafer W is small. If the number of the shot areas is large, the aforementioned EGA method is desirable from the point of view of preventing a decrease in throughput.

[0100]

The first embodiment has also been described such that the first robot arm 20 moves one stage, WS1, among three locations, i.e., the first, second and third positions, while the second robot arm 22 moves the other stage, WS2, among the three locations, i.e., the first, second and third positions. However, the present invention is in no way limited to this configuration. It is permissible, for example, to employ a method by which one robot arm 20 carries the stage WS1 (or WS2) to a position other than the first, second or third position and frees it there during its carriage from the first position to the third position, while the other robot arm 22 moves this stage WS1 (or WS2) from this position to the third position. This makes it possible to use one

robot arm 20 exclusively for carriage between the second and first positions of both stages, and use the other robot arm 2 exclusively for carriage between the third and second positions of both stages.

[0101]

Also, each laser interferometer constituting the interferometer system 26 may be a multi-axis interferometer which can measure not only the rectilinear positions of the wafer stage in the X- and Y-direction, but also its pitching or yawing.

[0102]

[Second embodiment]

Next, the second embodiment of the present invention will be described with reference to FIG. 5. The constituent parts identical with or comparable to those in the first embodiment will be assigned the same numerals or symbols, and their explanations will be omitted.

[0103]

The second embodiment is characterized in that a wafer stage WS1 is constituted to be divisible into two parts, i.e., a stage body WS1a and a substrate holding member WS1b detachably mounted on the stage body WS1a and having the same shape as the stage body WS1a; and that likewise, a wafer stage WS2 is constituted to be divisible into two parts, i.e., a stage body WS2a and a substrate holding member WS2b detachably mounted on the stage body WS2a and having the same shape as the stage body WS2a.

[0104]

On the substrate holding members WS1b, WS2b, the wafer W is held by suction via a wafer holder (not shown). Reflecting surfaces functioning as moving mirrors for an interferometer are formed on the side surfaces thereof. On these substrate holding members WS1b, WS2b, reference mark plates FM1, FM2 are provided, respectively, on their upper surfaces.

[0105]

In this second embodiment, parallel processing is performed on the wafer stages WS1, WS2 in practically the same manner as in the aforementioned first embodiment. At a time when an alignment action is completed on one stage side, and an exposure action is completed on the other stage side, the main control device 28 controls a first and a second robot arm 20, 22. As a result, the substrate holding member WS1b (or WS2b) on the alignment-completed stage side is carried (moved) onto the stage body WS2a that has stopped at the first position. In parallel, the substrate holding member WS2b (or WS1b) on the exposure-completed stage side is carried onto the stage body WS1a that has stopped at the second position. In this manner, the substrate holding members WS1b, WS2b are replaced. During replacement of the substrate holding members WS1b, WS2b, the measuring axes of

an interferometer system 26 are interrupted, making the position control of the wafer stages WS1, WS2 impossible. During this period, stage stoppers 30a, 30b appear and hold the stage bodies WS1a, WS2a in place. In this case, wafer replacement is performed at the second position by a carrier arm (not shown).

[0106]

In the present second embodiment, as will be easily imagined from FIG. 5, the position at which the mark WM on the reference mark plate FM lies in the detection area of the alignment microscope WA is determined as the second position; whereas the position at which the mark RM on the reference mark plate FM lies in the projection area of the projection optical system PL is determined as the first position. Thus, the main control device 28 carries out the movement of the substrate holding members WS1b, WS2b onto the stage bodies, resetting of the measuring axes of the interferometer system 26, and the R-SET or W-SET.

[0107]

The second embodiment can obtain the same effects as the above-mentioned first embodiment.

[0108]

The second embodiment has been described such that the first and second robot arms 20, 22 move the substrate holding member between the first and second positions. However, as in the first embodiment, the first and second robot arms 20, 22 may move the substrate holding member among three locations, i.e., the first, second and third positions. In this case, wafer replacement can be performed at a site unrelated to the projection optical system PL or the alignment microscope WA. Hence, even if the working distance below the alignment microscope WA is narrow, for example, there are no disadvantages such as the alignment microscope WA impeding wafer replacement.

[0109]

The first and second embodiments have been described such that the robot arms or the stage stoppers are used as measures during the interruption of the measuring axes of the interferometer system 26. The present invention is not limited to this configuration. For instance, a two-dimensional grating may be etched on the lower surface of the wafer stage, so that the position can be read by an optical encoder from below the stage travel surface. Alternatively, there may be employed means capable of precisely moving the stage to a next position once the interferometer measuring axes are interrupted, or means capable of holding the stage body at a predetermined position while stopping it there.

[0110]

The first and second embodiments have also been described such that two wafer stages movable independently are provided. However, three or more wafer

stages which are movable independently may be provided. If three wafer stages are provided, an exposure action, an alignment action, and a wafer flatness measuring action, for example, can be performed in parallel. There may be a plurality of the projection optical systems PL and alignment microscopes WA. If a plurality of the projection optical systems PL is present, an alignment action and two different patterns of exposure actions can be performed in parallel. This is suitable for double exposure or the like.

[0111]

The above embodiments have been illustrated in which the present invention was applied to a step-and-repeat type projection exposure apparatus. However, the range of application of this invention is not limited to this configuration. This invention is applicable not only to a step-and-scan type projection exposure apparatus, but to other types of exposure apparatuses, such as an electron beam direct drawing device.

Effects of the Invention

[0112]

As explained above, according to the first aspect of the invention, it possible to provide an excellent exposure method capable of determining the size of the substrate stage irrespective of the amount of base line while improving the throughput, which has not been obtained in the prior art.

[0113]

Furthermore, according to the second to eleventh aspects of the invention, it is possible to improve the throughput by the parallel process of an exposure action on one substrate stage and an alignment action on the other substrate stage.

Brief Description of the Drawings

FIG. 1

FIG. 1 is a view schematically showing the entire structure of an exposure apparatus according to the first embodiment.

FIG. 2

FIG. 2 is a schematic plan view of one wafer stage of FIG. 1.

FIG. 3

FIG. 3 is a schematic plan view of the apparatus of FIG. 1.

FIG. 4

FIG. 4 is a view showing a flow of actions in the apparatus of FIG. 1.

FIG. 5

FIG. 5 is a schematic plan view showing the structure of a main part of an exposure apparatus as the second embodiment.

Description of Symbols

14X, 18X X fixed mirror (fixed mirror)

14Y, 18Y	Y fixed mirror (fixed mirror)
20	first robot arm (moving means)
22	second robot arm (moving means)
26	interferometer system
28	main control device (controller)
50	carrier arm (a part of a substrate carrier mechanism)
52A, 52B	reticle alignment microscopes (mark position detector)
100	exposure apparatus
WS1a, WS2a	stage body
WS1b, WS2b	substrate holding member
FM1, FM2	reference mark plates
WM, RM	reference marks
R	reticle (mask)
W	wafer (sensitive substrate)
PL	projection optical system
WS1	wafer stage (first substrate stage)
WS2	wafer stage (second substrate stage)
WA	alignment microscope (alignment system)
Xe	first measuring axis
Ye	second measuring axis
Xa	third measuring axis
Ya	fourth measuring axis

FIG. 1

28 MAIN CONTROL DEVICE

FIG. 4

WAFER STAGE WS1
WAFER EXCHANGE INTERFEROMETER RESET W-SET
WAFER ALIGNMENT
INTERFEROMETER RESET R-SET
EXPOSURE
WAFER EXCHANGE INTERFEROMETER RESET W-SET
WAFER ALIGNMENT

WAFER STAGE WS2
INTERFEROMETER RESET R-SET

EXPOSURE
WAFER EXCHANGE INTERFEROMETER RESET W-SET
WAFER ALIGNMENT
INTERFEROMETER RESET R-SET
EXPOSURE